Direct photons at low p_T measured in PHENIX

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Abstract. Direct photon spectra measured at small p_T in p+p, d+Au and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV are presented. Several measurement techniques including statistical subtraction, tagging, and internal and external conversion were applied and found to produce consistent results. The p+p and d+Au results are found to be in very good agreement with pQCD predictions over the entire p_T range. The direct photon yield in Au+Au collisions is compared to binary scaled d+Au data but the large systematic errors on d+Au results do not allow to draw conclusions on the presence of a direct photon excess due to matter-related emission in Au+Au collisions.

1. Introduction

Due to their extremely large mean free path length direct photons are considered as an excellent tool to explore the initial state of p+p and A+A collisions, to study nucleon structure functions and their modification in nuclei. But the most exciting application of direct photons is the possibility to deduce the temperature of the hot matter created in A+A collisions and to extract its equation of state. Due to the power-law form of the spectrum of hard prompt photons they will dominate at high p_T while matter-related direct photons can be observed only in the soft p_T region. Despite the considerable progress in the theoretical description of direct photon production in p+p collisions in the last 10 years [1], theoretical calculations are still not very reliable at small photon momenta and to account for the prompt photon contribution in A+A collisions we need a baseline – direct photon spectra measured in p+p and d+A collisions.

Direct photon extraction is an extremely complicated experimental task because the contribution of direct photons is only a few percent of the total photon yield and it rapidly decreases at small p_T. The dominating photon source is final hadron decays, $\pi^0 \rightarrow 2\gamma$, $\eta \rightarrow 2\gamma$ etc. Having a variety of detector subsystems, PHENIX has developed a set of approaches to increase the S/Bg ratio and decrease the systematic error.

2. Data analysis and results

The results presented here were taken in the 2003 RHIC run 3 (p+p and d+Au) and 2004 run 4 (Au+Au) with the PHENIX setup for each run described in [2] and [3],

* For the full list of PHENIX authors and acknowledgements, see Appendix 'Collaborations' of this volume

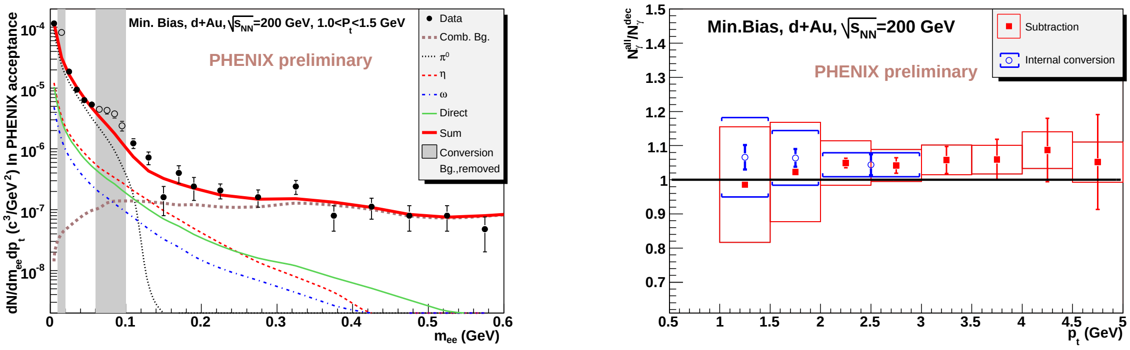
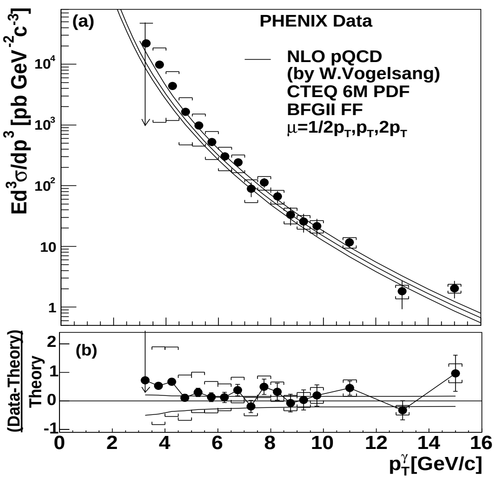


Figure 1. Left plot: Di-electron mass distribution, measured in minimum bias d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV in the PHENIX acceptance, decomposed into contributions from combinatorial background, meson Dalitz decays, and direct photon internal conversion. The two grey bands show regions contaminated by external conversion and excluded from the fit. Right plot: Ratio of inclusive to decay photon yields measured in same collisions by two methods.

respectively. The analysis is based on integrated luminosity of 266 nb^{-1} of p+p events, $\approx$ 3 billion d+Au events, and $\approx$ 900 M Au+Au events.

To produce the direct photon spectrum we measure the inclusive photon yield and subtract the decay photon contribution. The inclusive photon spectrum is measured with the electromagnetic calorimeter. Charged hadron contamination is removed by a cut on the distance to a projection of charged hit measured in the pad chamber, while neutral hadron contamination is estimated by analyzing the calorimeter response to identified charged hadrons and full GEANT simulations. In addition, very efficient shower shape and time-of-flight cuts are applied reducing the contamination of neutral hadrons from $\sim 30\%$ to $3-5\%$ at low p_T. Finally, acceptance, efficiency, conversion loss, and other corrections are applied to produce the inclusive photon spectrum.

With the variety of detector subsystems present in PHENIX several alternative techniques can be applied to remove decay photons. The basic technique – subtraction – includes measurement of the π^0, η and ω meson spectra, calculation of the spectrum of decay photons with Monte Carlo simulations, and subtraction of the decay photon spectrum from the inclusive photon spectrum [2]. In another technique – tagging – photon pairs with mass close to the π^0 mass are removed from the inclusive photon spectrum. Corrections are then applied for fake partners, missing partners, and heavier meson decays contributions [2]. An important extension of the tagging technique is the external conversion method. Its key feature is the measurement of the tagged photons using external photon conversion on the material of beam pipe. Imposing a cut on orientation of the e^+e^- pair in the magnetic field, we remove combinatorial background and contributions from Dalitz decays producing a very clean inclusive photon sample. Then decay photons are removed applying a standard tagging technique taking partner photons registered in the calorimeter.



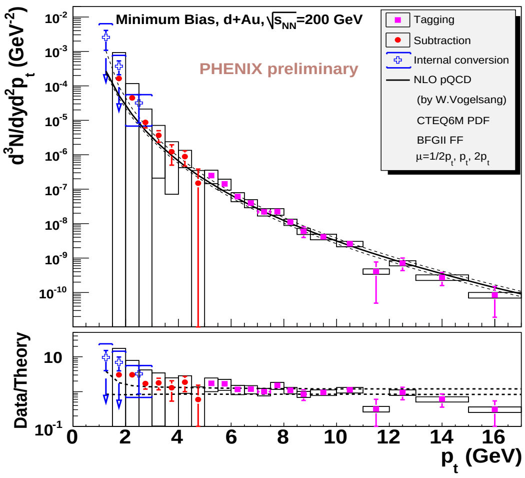


Figure 2. Left plot: Direct photon production cross-section measured in p+p collisions at $\sqrt{s_{NN}} = 200$ GeV [2] compared to pQCD predictions. Right plot: Direct photon yield measured by three methods in minimum bias d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV compared to binary scaled pQCD predictions [1].

Due to the small signal/background ratio both the tagging and subtraction approaches produce relatively large systematic errors. Errors can be considerably reduced using the internal conversion method. This method is based on the fact that any system emitting real photons emits virtual photons that convert to e^+e^- pairs with a universal m_{ee} distribution as $m_{ee} \to 0$ [4]. On the other hand, the di-electron mass cannot exceed the mass of the decaying system. Therefore measurement of the proportion of direct virtual photons at $m_{ee} > 100$ MeV excludes the $\pi^0 \to \gamma e^+e^-$ contribution and thus increases the signal/background ratio by ~ 10 times. This technique is illustrated in Figure 1. The di-electron mass distribution is fitted with the sum of the measured combinatorial background and the simulated contributions of virtual decay and direct photons. This fit has two free parameters: the proportion of direct photons and the absolute normalization of the simulated contributions. It's seen that at $m_{ee} \lesssim 100$ MeV the direct photon contribution is quite small while at higher mass it becomes comparable with the other contributions.

The ratio of inclusive photons over decay photons in d+Au collisions was extracted using the internal conversion and subtraction techniques (see Figure 1). Good agreement is found between the two approaches. The systematic errors in the case of the internal conversion method are not as small as recently reported in an analysis of Run 4 Au+Au collisions [3]. The reason is that the PHENIX setup in Run 3 was not optimized for this measurement: a huge background (dashed area in left plot of Figure 1) was produced due to external conversions on the MVD vertex detector, removed in later runs.

The direct photon spectra measured in p+p [2] and d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV is compared with binary scaled NLO pQCD predictions [1] in Figure 2. In both cases good agreement with theory is found over the entire p_T range suggesting an absence

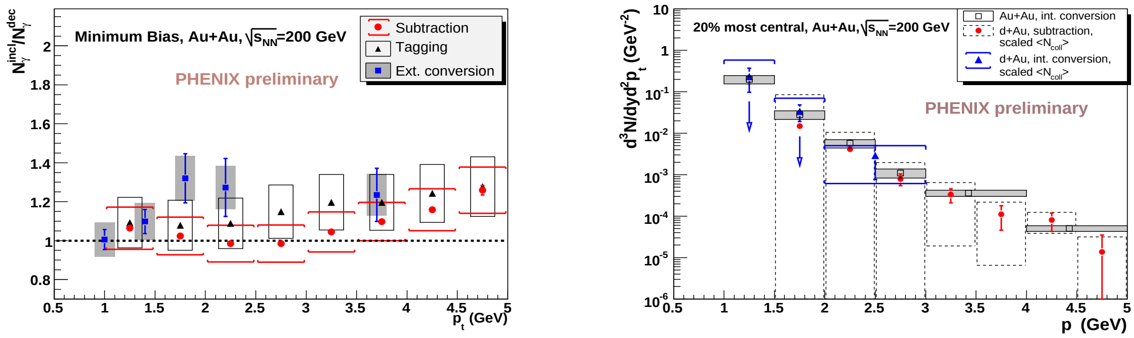


Figure 3. Left plot: Ratio of inclusive to decay photon yields measured in min. bias Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV by subtraction [5], tagging and ext. conversion methods. Right plot: The direct photon spectrum measured in central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV [3] compared to the binary scaled direct photon yield in d+Au collisions at the same energy.

of strong nuclear effects in d+Au collisions. The ratio of inclusive photons over decay photons in Au+Au collisions was extracted using subtraction [5], tagging and external conversion methods, see Figure 3. All three methods produce consistent results and comparable systematic errors while external conversion produces the smallest errors at small p_T. Taking the direct photon yield measured in d+Au collisions as a baseline we can estimate the prompt hard photon contribution in Au+Au collisions and search for excess direct photons radiated from the hot matter. In Figure 3 the direct photon yield in the 20% most central Au+Au collisions [5] is compared to the scaled d+Au collision results. Unfortunately, the systematic errors on the d+Au results are too large to draw a meaningful conclusion about a possible excess contribution due to thermal radiation.

3. Conclusions

We present the measured direct photon yields in p+p, d+Au, and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. PHENIX has developed a variety of methods to extract the direct photon yields and all provide consistent results. Both in p+p and d+Au collisions we find agreement with binary scaled NLO pQCD predictions within errors. The binary collision scaled yield in d+Au collisions is in agreement with the yield measured in Au+Au collisions. The large systematic errors do not allow to draw conclusions on the presence of a direct photon excess due to matter-related emission in Au+Au collisions.

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